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Experimental Observations of Extended Growth of 4H-SiC Webbed Cantilevers

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Abstract. We report on further observations of homoepitaxially grown 4H silicon carbide (SiC) cantilevers on commercial on-axis mesa patterned substrates. Mesa shapes with hollow interiors were designed to significantly increase the ratio of dislocation-free cantilever area to pregrowth mesa area. Mesas that did not contain axial screw dislocations (SD's) continued to expand laterally until uncontrolled growth in the trench regions rises up to interfere / merge with the laterally expanding cantilevers. Molten KOH etching revealed high defect density in regions where trench growth merged with the laterally expanding cantilevers. The remaining portions of the cantilevers, except for central coalescence points, remained free of dislocations.

Introduction

It is well known that micropipe defects are fatal to SiC electronic power device operation. However, many other crystal defects permeate SiC substrates and epi-layers causing some SiC devices to operate below theoretical limits and / or suffer from reduced reliability [1]. We have previously reported on the formation of thin cantilevers and webbed regions to produce small device sized regions of dislocation free SiC [2]. This work reports on further observations of continued cantilever expansion over larger areas on pregrowth mesa shapes with enclosed hollow interiors.

Experimental

The substrates were commercial, 4H-SiC, on-axis (typically within 0.3° of the basal plane), n-type, Si face. The substrates were patterned with an array of mesa shapes via dry etching by the wafer vendor [3]. The shapes of the mesas were designed to minimize the probability of including SD's in the pregrowth mesa while maximizing cantilever growth. The shapes of the mesas consisted primarily of singular hollow hexagons (Fig. 1, mesas A and B) or multiple conjoined hollow hexagons (Fig. 1, mesas C and D). The line width and height of the mesa support structures was nominally 5μm and 20μm, respectively. In one orientation, the vertical etched sides of

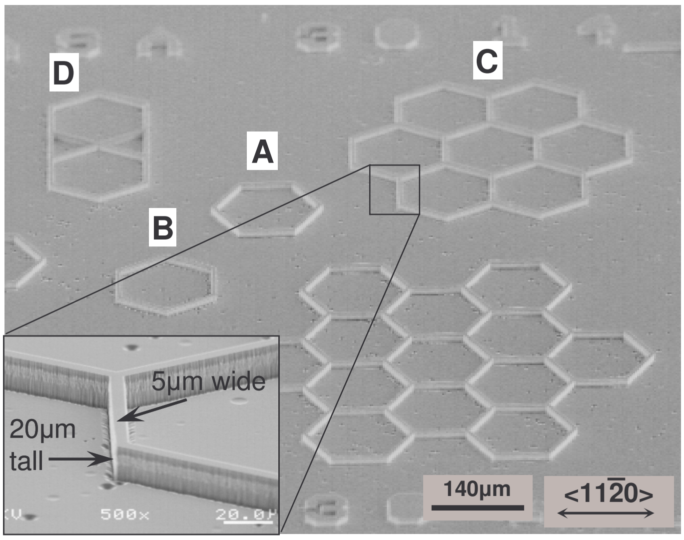

Fig. 1. Pregrowth hexagonal shaped mesas with hollow interiors. Notice the orientation of the mesas A and B with respect to crystallographic directions.

the hollow hexagons are $(1\bar{1}00)$ facet faces (Fig. 1, mesa A), while in the second orientation the vertical sides of the mesa form $(11\bar{2}0)$ surfaces (Fig. 1, mesa B).

Immediately prior to the first growth the quarter wafer sample was piranha cleaned. The growth experiments were conducted in a horizontal-flow cold-wall chemical vapor deposition (CVD) reactor [4]. Silane (SiH_4) and propane (C_3H_8) were used as the growth precursors with H_2 as the carrier gas. An in situ etch in pure H_2 was conducted at ~1000 mb, ~1640°C for 4 minutes immediately preceding growth. Growth was carried out at 200 mb at ~1640°C with 9 sccm of SiH_4 and 1.5 sccm C_3H_8 (C/Si = 0.5) diluted in 8 slm of H_2. The first growth run was 240 minutes. A second run of 50 minutes with identical parameters was performed on the same sample to further expand the cantilevers that developed in the first growth run. Pure step-flow growth conditions were maintained for the duration of both growth runs.

The as grown sample was photo-documented using an optical microscope with Nomarski differential interference contrast (DIC) optics. Selected areas were analyzed with a Digital Instruments Dimension 3000 atomic force microscope in tapping mode. Defects were decorated by multiple molten KOH etches totaling 45 minutes at 500°C. For comparison, the sample was documented after KOH etching by optical and scanning electron microscopy.

Results and Discussion

At the completion of the growth phase, mesa shapes showed several distinct morphological behaviors depending upon the dislocation content and crystallographic orientation of each given mesa. Mesas that were threaded by one or more SD's exhibit high vertical c-axis growth (Fig 2. mesa D), consistent with previous observations [2]. Higher index crystal facets develop as the mesa grows, which appear as the optically dark areas in Fig. 2 around mesa D.

When mesas are not threaded by SD's, large horizontal thin cantilevers evolved (Fig 2. mesas A and B). Comparing mesa A with mesa B, it is clear that the extent of lateral expansion of cantilevers is influenced by the crystallographic orientation of the original mesa support structure. Mesa A did not achieve complete coalescence leaving a visible hole in the cantilever that is forming a roof over the hollow interior of the mesa. Mesa B is oriented to take advantage of the more rapid growth in the $<11\bar{2}0>$ direction for hexagonal SiC, which enabled full coalescence to a single central location forming a complete roof over the hollow interior of mesa B.

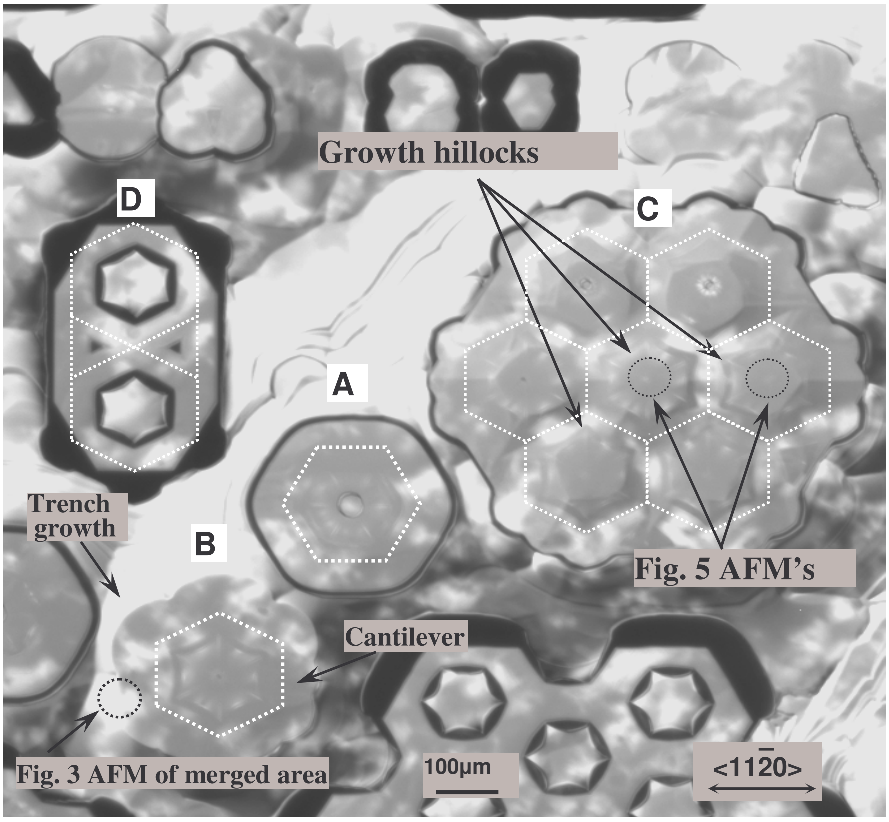

Fig. 2. After growth large cantilevers have formed on mesas A, B and C. White dashed lines indicate the approximate location of the original mesas. Mesa D failed to develop cantilevers and grew vertically due to SD's.

Lateral cantilevers along the outer periphery of mesa B merged with rising trench growth, as shown in Fig. 2. AFM analysis of a merged region is shown in Fig. 3. At the interface between the cantilever of mesa B and the trench region the steps appear to pile up creating a ridge which appears as the white diagonal line in Fig. 3. A SD was identified as the top most source of steps very near the apparent cantilever edge and shows up as a corresponding etch pit in Fig. 4.

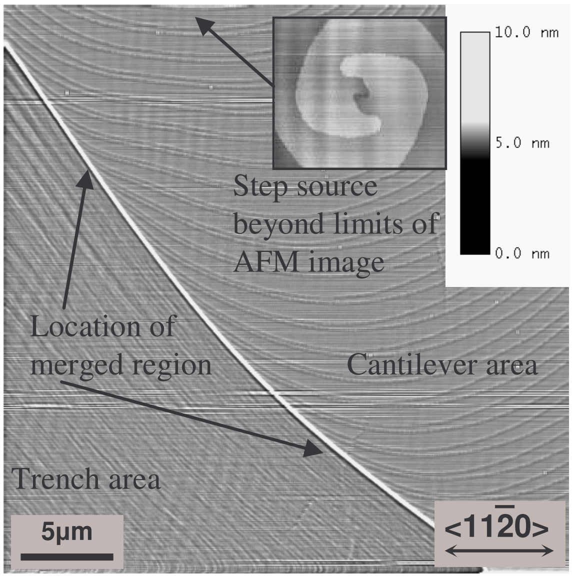

Fig. 3. AFM of trench growth merging with expanding cantilever of mesa B.

After completion of KOH etching, a high density of etch pits are observed around the outside perimeters of mesas A and B (Fig. 4). Notice that for mesas A and B, etch pits are observed only on the exterior of the mesas. The density of these outer edge etch pits are much greater than etch pit densities elsewhere on the sample. These etch pits indicate that new dislocations are being formed where trench growth rises up and merges with the expanding cantilevers. Based upon the geometry of the etch pits and AFM data we contend that some dislocations generated by the merging process are threading edge dislocations. Note the linear arrangement of etch pits arrayed along <$11\bar{2}0$> directions (i.e., parallel with $\{1\bar{1}00\}$ facets) in the top and upper left sides of mesa B (Fig. 4). This arrangement is consistent with stress induced edge dislocation behavior previously observed in SiC boules [5]. While SD's were observed at the outermost edges of cantilevered regions such as in (Fig. 3 inset), it was not determined if these are existing substrate SD's or if new SD's were formed by the cantilever / trench merging process. The complete absence of etch pits on the interior of mesas A and B in Fig. 4, is presumably because the trench growth has not merged with the interior cantilevers.

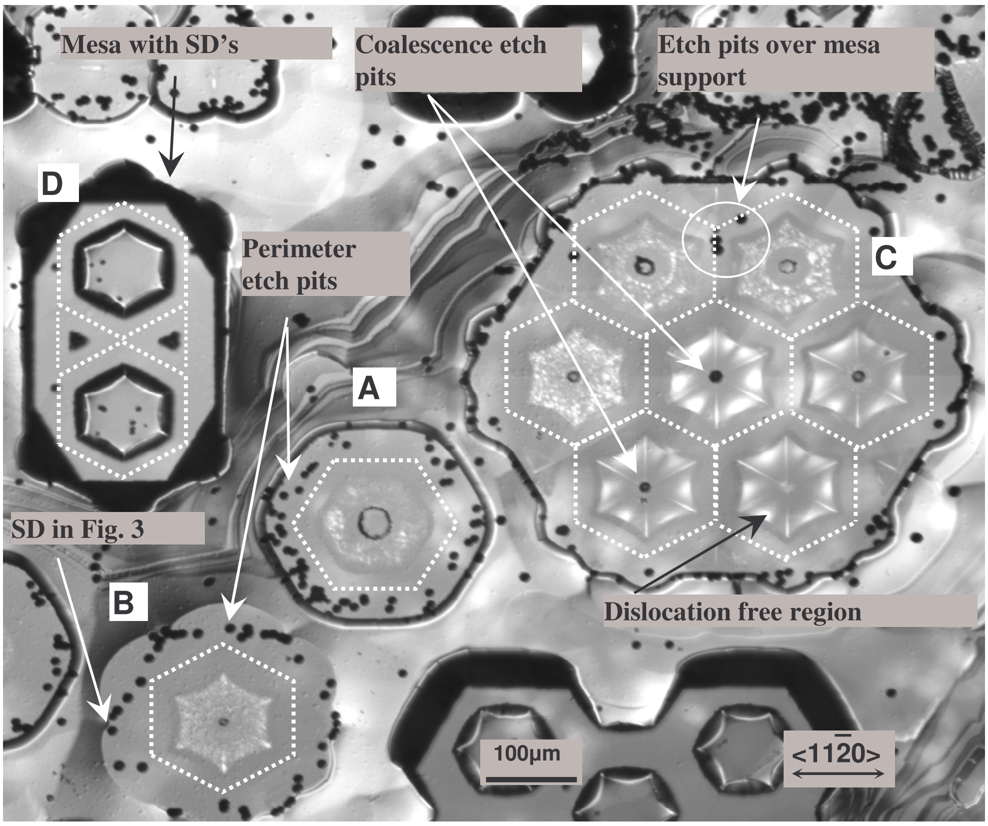

Fig. 4. Development of etch pits after KOH etching. White dashed lines indicate the approximate location of the original mesas. High density of etch pits form on the exterior regions of mesas A and B. Etch pits form at the central coalescence point(s) of mesas B and C. Notice no etch pit forms over the dislocation free region of mesa C.

When SD's are

confined within the hollow region(s) (Fig. 2, mesa C) the SD's will be translated to a central point of cantilever coalescence, as previously reported in [2]. The relocated SD's will act as a new step-source enabling vertical growth in the c-axis direction to resume, forming growth hillocks. This can be seen in the indicated areas of mesa C of Fig. 2. The Fig. 5 AFM image of the central coalescence point of the center of mesa C confirms the presence of a relocated SD. As expected, an etch pit forms at this location as can be seen in Fig. 4, mesa C. Hillocks do not form at every point of coalescence. If a particular area bounded by the mesa does not confine any dislocations, the cantilevers may achieve perfect coalescence, with a dislocation free cantilever being formed. The lower right hollow region of mesa C in Fig. 4, demonstrates this, as no etch pit formed after KOH etching. In the upper portion of Fig. 4 mesa C, several threading edge dislocation etch pits reside directly over the original support mesa with no impact on cantilever development [2]. Complete cantilever coalescence was not achieved in the top two hollow regions of mesa C. Once the SD in the center cell of mesa C formed, as described above, lateral cantilever expansion in the other adjacent cells that have not completely coalesced, slows down due to vertical growth and steps formed by the center cell SD.

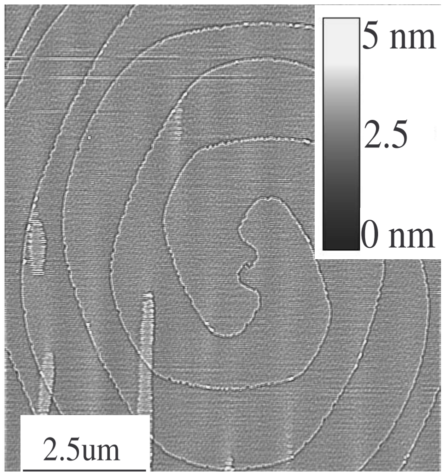

Fig. 5, High pass filtered AFM of the center of mesa C (Fig. 2 and Fig. 4), showing 0.5 nm height spiral steps emanating from relocated SD.

Conclusion

Lateral expansion of homoepitaxial cantilevers can be used to effectively increase the area of dislocation free SiC. Proper selection of mesa shape and orientation can be employed to increase the cantilever expansion rate. Cantilevers that do not merge with trench growth remain free of dislocations. If merging with trench growth can be suppressed through the use of a selective epitaxial growth mask, lateral expansion of dislocation free cantilevers should be possible, provided pure step-flow growth conditions are maintained.

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